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THE INSTITUTE OF BREWING RESEARCH SCHEME.

TIMBER INVESTIGATIONS.

REPORT ON THE AMERICAN OAK WOOD USED IN THE CONSTRUCTION OF BEER CASKS.

BY

PERCY GROOM, M.A., D.Sc.

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I.

Report on the American Oak Wood used in the Construction of Beer Casks.

By Percy Groom, M.A., D.Sc.

Professor of the Technology of Woods and Fibres, Imperial College of Science and Technology, London, S.W.

This work was done in co-operation with Miss Elsie Cadman, B.Sc., who was solely responsible for the mechanical side of the work, the making of cultures, and the initial identification of the samples of wood and micro-organisms.

Beer stored in casks made of American oak in some cases deteriorates rapidly, becoming distasteful and acquiring an abnormal scent; yet in other cases the beer undergoes no such disagreeable change. Throughout this Report casks causing the former effect are termed *unsatisfactory*, and the others *satisfactory*.

The immediate cause of the deterioration of the beer must be a change in the chemical composition of this; such a change must be due either to the occurrence of a tainting substance or to the destruction of one or more flavouring ingredients that are normally present, or to both these causes.

A substance directly or indirectly causing tainting might :—

(*a*) Be present originally in the wood and ooze into the beer as an extractive.

(*b*) Be manufactured by fungi or bacteria usually foreign to beer, which gain entrance to the wood, with or without living in the beer itself.

(*c*) Be manufactured by fungi or bacteria which are normally present in beer, but which produce abnormal ingredients owing to changed conditions (induced by the entry of extractives or of air).

Similarly the destruction of normal ingredients of the beer might be due to pure chemical action or to the action of micro-organisms.

It is thus obvious that the perviousness of the wood in the direction through the thickness of the staves or end-pieces may be of great importance, as controlling not only the oozing of beer outwards and possibly of wood-extractives inwards, but also the rate of passage of gases in both directions. An increase in perviousness might in turn be due to :—

(*a*) The use of sapwood.

(*b*) The use of a species of oak (for instance, a " Red Oak ") characterised by pervious wood.

(*c*) The cutting of the staves and end-pieces in a direction other than the true radial, that is to say, the use of wood not riven " on the quarter."

Investigations conducted.

Hence the botanical side of the research included investigations of both satisfactory and unsatisfactory barrels under the subjoined headings :—

(*a*) Fungi and bacteria in the wood and beer.

(*b*) Sapwood, its presence or absence.

(*c*) Mode in which the staves and end-pieces were cut.

(*d*) Structure of the woods used : their identification, porosity (perviousness) and chemical contents so far as these are readily identified by micro-chemical methods.

Material supplied and examined.

Five casks, including satisfactory and unsatisfactory examples, were kindly presented by Messrs. Barclay, Perkins and Co. ; H. & G. Simonds ; Truman, Hanbury, Buxton & Co. ; and Watney, Combe, Reid & Co. These in this paper are numbered from I to V (the numbering does not correspond to the order of succession of the names above given). In addition, pieces of staves of wood from which satisfactory barrels could, according to their opinion, be made, were kindly supplied by the following firms :—Messrs. W. J. Burton & Sons ; W. Butler & Co. ; J. D'Arcy & Son ; John Morris & Son ; H. & G. Simonds ; Tennant Bros. ; and Tomson & Wotton.

A.—THE WOOD.

I.—Sapwood.

The sapwood of the two common European oaks (*Quercus pedunculata* and *Q. sessiliflora*) is not used in the manufacture of barrels or casks intended to hold beer or wine. In the first place this sapwood is more pervious to liquids, so that beer and wine can ooze through it. (The cause of this is explained later in this Report.) In the second place the chemical composition of sapwood is different from that of heartwood. In particular the sapwood contains starch or sugar or both, and some protein substances, which are food-material for fungi and bacteria, and are more easily attacked than is wood-substance. These substances are more or less completely lacking in the heartwood of European oak. The heartwood of these species on the other hand is much richer in "tannin," so that with iron salts the heartwood turns black (dark blue or green), while the sapwood is not darker than the solution.

Where sapwood is used in the manufacture of wine-casks, as is well known, the wine acquires a musty flavour. This has been attributed to the action of fungi and, I believe, bacteria which penetrate the wood.

It therefore appeared possible that the American oak used in beer barrels might include sapwood and fungi or bacteria.

Many of the American staves contained large or moderate quantities of starch, so that the wood agreed with sapwood of the common European oaks; but, on the other hand, the American wood was always rich in tannin (and became black with ferric chloride), and abounded in tyloses (see later), nor could any protein bodies or protoplasm be found, and thus it agreed with the heartwood of the common European oaks. Hence in my opinion the staves were not made of sapwood that had been steamed so as to resemble heartwood, but consisted commercially of heartwood, though this often represented rather a coloured "ripe-wood" (which is transitional between sapwood and heartwood).

Despite the abundance of starch neither fungi nor bacteria were ever discovered inside the wood of the barrels.

Moreover, the spoilt beer did not include organisms foreign to good beer, at least in the cases examined (see the concluding section of this Report).

Conclusions.

(1) The barrels always consisted of wood that is commercially heartwood, but which was often rich in starch.

(2) Tainting was not due to fungi or bacteria acting in the wood or gaining access to the beer through the wood.

(3) And, as will be demonstrated later in this Report, the evidence was against the presence in the beer of fungi or bacteria that are foreign to good beer. Moreover, the rapidity with which beer deteriorated in unsatisfactory barrels harmonizes better with the assumption that the tainting is due to the entry into the beer of some disturbing substance extracted from the wood.

Consequently the examination of the structure and the identification of the woods used became doubly important.

II.—Mode of Cutting the Staves and End-Pieces.

For reasons given later in this Report, staves or end-pieces not cut radially (on the quarter) allow of greater diffusion of beer through the wood to the outside, and where the beer is not in contact with the wood, probably allow of freer passage of gases to and from the interior of the barrel. Thus the conditions under which the beer is stored are changed, and there may be set up abnormal chemical changes, and the beer may also become "flat."

In the barrels examined the direction of cutting was correct, excepting in the case of two unsatisfactory barrels, I and II. Nearly all the wood of Barrel II was wrongly cut, as were three end-pieces of Barrel I.

Conclusion.—The deterioration of the beer was not caused by the use of wood cut in an unsuitable direction.

III.—Structure.

It therefore appears probable that structural features or chemical contents of the wood, or both, are responsible for the deterioration of the beer.

To facilitate the investigation of the structure and identification of American oak woods, there were available :—

(1) My collection of American oak woods and microscope preparations of these.

(2) The undermentioned original works :—

Abromeit, J.: "Ueber die Anatomie des Eichenholzes." *Berlin*, 1884.

Sudworth, G. B., and Mell, C. D.: "The Identification of Important North American Oak Woods." *U.S.A. Forest Service, Bull.* 102, 1911.

Groom, Percy: (1) "The Evolution of the Annual Ring and Medullary Rays of *Quercus*." *Annals of Botany, XXV*, 1911.

(2) "The Oecology of Coniferae." *Annals of Botany, XXIV*, 1910.

(3) "A Preliminary Inquiry into the Significance of Tracheid-caliber in Coniferae." *Botanical Gazette, LVII*, 1914.

Typical structure of wood of a leaf-shedding (deciduous) oak.

In order to render clear the details discussed subsequently, it is necessary to consider the typical structure of the wood of an oak that casts its leaves annually.

The cross-section of a well-developed trunk of such an oak shows clearly *annual rings* arranged concentrically round the centre, and crossing them at right angles broad *medullary rays* (Figs. 1 and 2). The outer wood, *sapwood*, lighter in colour, is composed of a number of annual rings, as is the darker, more central wood, *heartwood* (Fig. 1).

Structure of the annual ring.

It is the structure of the individual annual ring that affords the means of identifying the species of oak, since in each species it is characteristic, though subject to variations.

Spring-wood and Pore-zone.

In cross-section the first-formed wood, which is at the inner boundary of each annual ring, shows a zone of wide "*pores*," which are the cut ends of relatively wide and long tubes, known as "*vessels*." This zone of wide vessels, together with the connecting narrower constituents, is the "*pore-zone*" and "*spring-wood*" (Figs. 3 and 4).

There may be one or more concentric series or rows of these wide pores in the pore-zone ; and the number of series aids in the identification, since certain species are often characterised respectively by 1, 2-3, and 3-5 series.

In cross-section the shape of the pore varies from circular to oval or elliptical ; in the last two cases the long axis being radial or tangential to the annual ring.

Again in the width of these wide pores there are more or less characteristic differences in the various species of oaks.

Summer-vessels or Summer-pores.

The part of the annual ring produced later in the year and therefore lying outside the spring zone is known as the " *summer-wood* " (" *autumn-wood* ") (Figs. 3 and 4).

Passing outwards from the pore-zone in cross section, the vessels (pores) dwindle in size either gradually or more abruptly. They do not form concentric series (parallel to the outline of the annual ring), but are grouped in more or less distinct *radial series*, which are thus parallel to the medullary rays (Figs. 3 and 4).

Each radial series of narrow pores may be narrow and remain separate, or it may widen out and towards the outer part of the annual ring, thus tending to be fan-shaped (in cross-section), and join the two adjoining radial series. In this latter case the outer part of the summer-wood shows narrow vessels, scattered more or less evenly but distantly.

Details used in identification concerning these summer-vessels are also: the proximity of the outer end of the radial series to the outer boundary of the annual ring, the diameter of these vessels, especially when compared with the spring-vessels; and the gradual or sudden nature of the decrease in calibre of the vessels in passing from spring-wood to summer-wood of one annual ring.

Tyloses.

In the sapwood the vessels have their cavities more or less completely unobstructed, so that the pores are " open " ; but in the heart-wood minute bladder-like structures may grow from the surrounding tissue (parenchyma) into the cavities of the vessels and more or less thoroughly plug these. In the heartwood of American " Red Oak," these tyloses are feebly developed, so that liquids and gases more readily pass through the wood. Accordingly the timber of " Red Oaks " is not suited for the manufacture of staves or end-pieces, but is used for the spiles or pegs. The heartwood of the common European oaks and American White Oaks, on the contrary, has its vessels richly blocked by well-developed tyloses (Fig. 5), so that it is relatively impervious to liquid along its grain. Consequently in the United States only " White Oaks " are suitable for the manufacture of casks that store alcoholic beverages.

Tracheides and fibro-tracheides.

The remaining wood of the annual ring, or timber as a whole, is mainly composed of much narrower and shorter, yet more or less fibre-shaped, hollow constituents, elongated in the direction of the grain of the wood. These, if possessing thin walls, are termed *tracheides*, but if having thick walls are known as *fibro-tracheides*. In the summer-wood they form compact masses between the radial series of vessels, where

they are interrupted only by the medullary rays and by the constituents described in the next paragraph, namely parenchyma. Especially fibro-tracheides give strength and weight to oak timber.

Parenchyma.

In a cross-section of a solid piece of oak timber, the vessels appear as black dots, the tracheides and fibro-tracheides as brown ground-work, while the soft tissue or parenchyma stands out as lighter, even whitish, lines or bands (Fig. 4). It may be seen forming (with tracheides) a light halo round the radial series of summer-vessels, and as narrow lines running at right angles to the medullary rays (*i.e.*, *tangential* to the annual rings) through the masses of fibro-tracheides of the summer-wood. The parenchyma tissue consists of very short and narrow, brick-shaped, pulp-like cells, elongated in the direction of the grain of the wood (Fig. 6). Each cell in the sapwood contains living substance (protoplasm), largely protein in composition, and sugar or starch or both. These, together with the medullary rays, are the constituents that contain starch in the wood of the American staves. The tangential lines of parenchyma may be composed of one or two series of cells, and may be quite distinct or interrupted, so that in extreme cases the tangential arrangement cannot be recognised. The exact pattern formed by these cells in cross-section facilitates identification of the species.

Medullary rays.

These are bands or ribbons of parenchyma cells running across the grain, radially from the outside towards the centre of the original tree trunk (Figs. 6 and 7). On the radial face of the wood, therefore on the faces of the stave, they are the structures comprising the lustrous "silver grain" (Fig. 6). These parenchyma cells are elongated in a direction at right angles to the grain, and are thus distinguishable from the wood-parenchyma, with which they agree as regards contents (starch, etc., in sapwood and in American staves). The end-walls of these cells have well-developed, thin, window-like rounded patches—termed pits—through which liquids can readily pass. It is through these, at least largely, that liquids would pass out of a barrel if the staves were cut in a tangential instead of a radial direction.

There are two types of rays: very thin, one or more cells thick, and much deeper and thicker ones many cells thick (Fig. 7). The precise shape of these latter, as seen on the tangential face, differs in different species.

Diagnostic Tables.

As all the wood examined was found to be derived from species that cast all their foliage leaves annually, the Tables given below refer solely to such species :—

Table I. (From **Sudworth and Mell.**)

White Oaks.	*Red Oaks.*
Pores abruptly diminish in diameter from the spring-wood to the summer-wood.	Pores gradually diminish in diameter from the spring-wood to the summer-wood.
Tyloses present, and generally well developed.	Tyloses absent, or small or scanty.

As all the wood examined was the produce of the group "White Oaks," the succeeding Table refers solely to that group. It includes in particular all the species mentioned as being used in the manufacture of beer-barrels and whiskey casks, viz., *Q. alba*, *Q. minor*, *Q. platanoides*, *Q. macrocarpa* and *Q. acuminata*.

There are, however, certain facts that render difficult the use of such Tables. In the first place the structure of the annual ring of one individual oak tree varies according to the position that it occupies in the trunk, and in one and the same species according to the conditions under which it was grown. It therefore becomes necessary to examine many specimens of each species before exact diagnostic features can be discovered; indeed, up to the present it has been found impossible to find structural features distinguishing the woods of the two common European oaks (*Q. pedunculata* and *Q. sessiliflora*). Such a laborious and comprehensive examination of American oak timbers has apparently not been conducted, and could be conducted only in the United States of America.

The limitations in connection with the usage of Table II are illustrated in the succeeding paragraphs.

The number of concentric rows or series of large vessels constituting the pore-zone of the spring-wood vary in the same species. Moreover, it is obvious that a wood having two such rows might belong to the first or second group, or a wood having three rows might belong to the second or third group.

Again, although the width of the largest vessels in the pore-zone affords some indication of the identity of a wood, there are considerable variations in one tree trunk, even at the same level.

Very important is the fact that when the wood is slow-grown and the annual rings are consequently narrow, the characteristic pattern is more or less obliterated: the porous zone usually occupies a larger proportion of the annual ring; the radial series of summer-vessels are apt to become broadened out (and oblique), so that their radial arrangement is more or less completely obscured (Fig. 5). These facts are very familiar in connection with the two common European oaks, and are excellently demonstrated by the illustration given by Sudworth and Mell of narrow-ringed and wide-ringed woods of *Q. platanoides*, *Q. macrocarpa*, and *Q. acuminata*, all of which show a strong likeness to the wood of *Q. alba*, and, like it, are said to be used in the manufacture of beer-barrels.

TABLE II.—WHITE OAKS.

- Pores in spring-zone mostly in 1 series, or rarely in 2 district rows. Pores in summer-wood, half the width of spring-pores, few and scattered.
- Pores in spring-zone in 1–3 concentric series. Pores in summer-wood less than half the width of spring-pores.
  - Pores in summer-wood ·05 m/m or less in diameter, and arranged irregularly or in *single* or *double* radial rows.
  - Pores in summer-wood more than ·05 m/m in diameter, and arranged chiefly in *single* radial rows.
    - Summer-pores radial series rarely reaching the periphery of the annual ring.
    - Summer-pores radial series reaching the periphery of the annual ring.
      - Spring-pores circular; diameter, ·15–·25 m/m.
        - *Q. minor.*
      - Spring-pores chiefly elliptical; diameters, ·2–·3 m/m.
        - *Q. platanoides.*
  - Pores in summer-wood very variable, and arranged chiefly in *double* radial rows.
    - Summer-pores large, and their radial series always reaching the periphery of the annual ring.
    - Summer-pores very irregular in diameter, radial series only rarely reaching the periphery of the annual ring.
      - Wood-parenchyma in summer-wood chiefly in conspicuous double tangential bands.
        - *Q. alba*..... Large medullary rays, about 4 m/m apart.
        - *Q. macrocarpa*... Large medullary rays, about 6 m/m apart.
      - Wood-parenchyma in summer-wood scattered rather irregularly, occasionally in short, parallel, inconspicuous tangential bands.
        - *Q. breviloba*, *Q. phellos*. *Q. lyrata*, *Q. Michauxii*.
- Pores in spring-zone in 3–5 concentric series.
  - Summer-pores walls thick; radial bands become narrower towards the periphery of the annual ring.
    - *Q. acuminata* (radial bands, 1 vessel wide chiefly).
    - *Q. imbricaria* (radial bands, chiefly 2 vessels wide).
  - Summer-pores walls thick; radial bands wider towards the periphery of the annual ring.

As a considerable number of the staves supplied for the present investigation had only very narrow annual rings, their exact identification was impossible (Fig. 5). Both satisfactory and unsatisfactory barrels included slow-grown staves and end-pieces.

Finally, in regard to the distance apart of the large medullary rays—or, as Abromeit recorded it, the number of rays per unit area—there is considerable variation in the same species (*cp.* the suggested distinction between *Q. alba* and *Q. macrocarpa*).

In fine the reference of a single piece of American oak to its exact species may be a matter of great difficulty, or, at present, of impossibility.

Even detailed measurements of the diameter, wall-thickness, etc., of the various constituents, give no crucial aid.

A number of the staves were made of the wood of *Q. alba* or a species close to it. But the difficulty in distinguishing these (even when the annual rings are wide enough) is clear when the subjoined Table III, giving the structure of the annual ring, is examined.

TABLE III.

	Q. alba.	*Q. macrocarpa.*
Spring vessels, number of rows	2–3	2.
,, ,, diameter	·3–·5 m/m	·4–·5 m/m.
Summer vessels, radial series	Narrow and radial	Broader and tending to be oblique.
,, ,, diameter	·05 m/m	·05 m/m.
Fibro-tracheides, diameter	·018 m/m	·021 m/m.
Parenchyma, arrangement	In tangential rows	In more distinct tangential rows.
Large medullary rays, distance apart	2–5 m/m	3–4 m/m.
Large medullary rays, width	·5–·7 m/m	·5–·7 m/m.
,, ,, ,, height	15–35 m/m	15–20 m/m.

It was therefore found impossible to identify with certainty the woods present, though they were closely allied in structure to those of *Quercus alba* and *Q. macrocarpa*.

Three types of wood presented themselves, and in slow-grown staves types that could not be referred definitely to any of the three. The distinctions among the three types are recorded below in Table IV.

TABLE IV.

Transverse Section.

	Type a.	Type b.	Type c.
Spring vessels.	Circular. Fairly close together.	Larger than in *a*. Tangentially oval. Far apart.	Radially oval. Crowded.
Summer vessels, radial rows.	Inclined to be oblique. Fairly far apart.	Very oblique. Much farther apart than in *a*. Narrow.	Straight and radial. Close together.

Table IV—*Transverse Section*—continued.

	Type a.	Type b.	Type c.
Parenchyma	In tangential bands which were rather indistinct, and usually consisted of more than one row of cells.	In tangential bands that were generally more distinct than in *a* and were less interrupted, and consisted of 1–2 rows of larger, more oval cells.	Scarcely showed any tangential arrangement, being very scattered.
Medullary rays.	——	Closer together than in *a*.	——
Occurrence in both kinds of barrels.	Common	Uncommon....	Common.

Whether these correspond to different species of oaks, or whether the distinctions were due to differences either in the position of the wood in the tree trunk or in the condition of growth of the tree, could not be decided.

All three types occurred in satisfactory and unsatisfactory barrels, as is shown by the detailed Tables given in the Appendix.

As a small number of pieces of unsuitable wood might cause a barrel to taint the beer, it was necessary to determine the relative percentages of the different kinds of woods in the satisfactory and unsatisfactory barrels.

The succeeding Table V gives the absolute and the percentage numbers of staves and end-pieces belonging to types *a*. *b*, *c*, and to the doubtful group (recorded under column " ? ") in the separate barrels, and the aggregate numbers in the satisfactory and unsatisfactory barrels, respectively.

It will be seen that in both satisfactory and unsatisfactory casks all three types of oak were present, and that in both kinds of casks type *a* preponderated in the staves, and type *c* was very dominant in the end-pieces.

Adding together the average percentages of the staves and end-pieces the following result is obtained :—

—	a	b	c	?
Unsatisfactory casks	51	25	94	30
Satisfactory ,, ...	49	15	94	42

The sole marked difference between the two is that in the satisfactory casks there is a decreased percentage of type *b*, and an almost equal increased percentage of the indeterminate type.

TABLE V.

No. of Cask.	Nature of Cask.	Staves. Number (N) and Percentage of Staves belonging to types a, b and c.									End-pieces.								
		N a	% a	N b	% b	N c	% c	N ?	% ?	Total. N	N a	% a	N b	% b	N c	% c	N ?	% ?	Total. N
I	Unsatisfactory	14	58	6	25	1	4	3	12	24	0	0	0	0	8	100	0	0	8
II	Unsatisfactory	8	38	3	14	6	29	4	19	21	1	12	0	0	6	75	1	12	8
III	Unsatisfactory	5	29	2	12	5	29	5	29	17	1	8	2	17	7	58	2	17	12
Total (Aggregate)	Unsatisfactory	27	44	11	18	12	19	12	19	62	2	7	2	7	21	75	3	11	28
IV	Satisfactory	9	43	4	19	3	14	5	24	21	2	20	0	0	7	70	1	10	10
V	Satisfactory	5	25	2	10	7	35	6	30	20	1	10	0	0	7	70	2	20	10
Total (Aggregate)	Satisfactory	14	34	6	15	10	24	11	27	41	3	15	0	0	14	70	3	15	20

But an inspection of the figures given in the preceding Tables in regard to the individual casks suggests that type *b* is not responsible for spoiling the beer, since Casks II and IV each had 21 staves, and in the former (satisfactory) three of these were made of type *b*, while in Barrel IV four of the staves belonged to that type: in both casks type *b* was unrepresented in the end-pieces.

The *conclusions* to be drawn from the *structure of the wood* are :—

(1) The exact identities of the woods present could not be determined.

(2) There was no recognisable difference in the composition of the satisfactory and unsatisfactory casks as regards structural types of wood present that could explain the different natures of the casks.

IV.—Chemical Contents.

Three kinds of chemical substances—starch, "tannin," and calcium oxalate—present in the wood are readily recognizable: the first by inspection, and by its blue coloration in iodine; the tannin by dark coloration with iron salts; and the calcium oxalate by mere inspection.

(A).—Starch.

The starch might be of significance from one or more points of view :—

(1) Starch, being generally more vulnerable than is wood to attack by fungi and bacteria, might facilitate or even render possible the entry of these into the wood, and thus indirectly cause the production of contaminating substances. (Such is supposed to be the case when wines are spoilt by the use of sapwood in wine-casks.)

But no such fungi or bacteria were found in the starch-containing cells.

(2) The amount of starch might vary directly or inversely with that of a substance that either contaminated or prevented contamination of the beer. (For instance, in living parts of plants when starch and "tannin" are stored side by side, decrease in the one is often accompanied by increase of the other.)

(3) The larger amount of starch in some pieces of heartwood of oak might be a specific character, and thus facilitate diagnosis of the species.

Against this suggestion in this particular case stands the fact that abundant starch was found in all three types *a*, *b* and *c*.

(4) Just as in the two common European oaks when starch is abundant in the sapwood it may be more or less completely absent from the heartwood, so in the American oaks in question starch might be abundant in heartwood that is younger (and therefore outer in old trunks or all the heartwood in younger stems), but absent from the more central older heartwood. In such a case it is conceivable that the age of the heartwood, and therefore its position in the standing tree, *deter*

mines whether or no it will contaminate beer. Thus the satisfactory or unsatisfactory nature of the wood might be a question of species and of age, or of either singly.

(5) The amount of starch in the sapwood of the two European oaks varies with the season of the year (and from year to year). It is therefore possible that the differences in the amounts of starch in the staves and end-pieces might have been due to *differences in the season of felling.*

I am informed that in the United States of America oak trees yielding staves are felled at all seasons of the year. If this be so it is possible that *one and the same species of American oak may yield satisfactory and unsatisfactory barrels according to the season in which it is felled.*

In the Appendix are given Tables including statistics of the amount of starch and calcium oxalate in the individual pieces composing the satisfactory and unsatisfactory casks, also in seven isolated pieces of wood alleged to yield satisfactory barrels. These are summarised in Tables VI and VII given below :—

M and **m** = much present.
F ,, **f** = a fair or moderate quantity present.
L ,, **l** = only a small quantity present.
O ,, **o** = none present.
LO ,, **lo** = little or none present.

A glance at the Tables in the Appendix shows that there is no correspondence between the type of wood on the one hand and the amount of starch or calcium oxalate on the other in individual staves : for instance, a stave of type *a* may show much, little, or no starch or calcium oxalate. The same conclusion is reached when the columns of Tables VI and VII, giving the type, starch contents, and calcium oxalate contents, are compared in any one cask. This latter examination is more reliable as mere inspection of sections is not a perfectly reliable method of estimating the amount of a chemical body present.

It is safe to conclude that in these staves and end-pieces *the amount of neither starch nor calcium oxalate, as gauged, is a specific character facilitating identification* of the different types of oaks represented.

TABLE VI.

Number of Pieces in each Cask.

Cask.	Totals.		Type of Wood.								Starch Contents.						CaOx Contents.					
	Sta.	End	Staves.				End-pieces.				Staves.			End-pieces.			Staves.			End-pieces.		
	—	—	a	b	c	?	a	b	c	?	M	F	LO	M	F	LO	m	f	lo	m	f	lo
I.—Unsatisfactory	24	8	14	6	1	3	0	0	8	0	7	3	14	0	5	3	6	4	14	2	1	5
II.—Unsatisfactory	21	8	8	3	6	4	1	0	6	1	8	7	6	3	1	4	6	7	8	2	3	3
III.—Unsatisfactory . ..	17	12	5	2	5	5	1	2	7	2	3	5	9	1	0	11	2	7	8	9	2	1
IV.—Satisfactory	21	10	9	4	3	5	2	0	7	1	0	2	19	0	0	10	8	10	3	6	2	2
V.—Satisfactory	20	10	5	2	7	6	1	0	7	2	0	0	20	8	1	1	14	4	2	2	3	5
Seven Satisfactory Pieces	—	—	0	0	4	3	—	—	—	—	0	1	6	—	—	—	4	2	1	—	—	—

TABLE VII.

Percentages of Types and Contents in all the pieces (staves and end-pieces) of each Cask.

Cask.	Type.				Starch.			Calcium oxalate.		
	a	b	c	doubt.	M	F	LO	m	f	lo
I.—Unsatisfactory	44	19	28	9	22	25	53	25	16	59
II.—Unsatisfactory	31	10	41	17	38	28	34	28	34	38
III.—Unsatisfactory	21	14	41	24	14	17	69	38	31	31
Average.—I, II, III	—	—	—	—	25	23	52	30	27	43
IV.—Satisfactory	35	13	32	20	0	6	94	45	40	16
V.—Satisfactory	20	7	47	27	27	3	70	53	23	23
7 pieces satisfactory	0	0	57	43	0	14	86	57	29	14
Average.—IV, V and 7 pieces	—	—	—	—	9	8	83	52	31	18

An examination of Table VII, giving the percentage figures of pieces having much, fair, or little or no starch or calcium oxalate, shows that in general, as judged by separate casks or by the average values, in the satisfactory casks there was less starch but more calcium oxalate.

But a comparison of the figures of the unsatisfactory Cask III and the satisfactory Cask V, gives the impression that the latter was richer in starch, or at least not poorer. Yet if the effect of a piece richer in starch or poorer in calcium oxalate in spoiling beer is due to some extractive substance varying in quantity directly or inversely with these substances, it is clear that the size of the piece of wood comes into question. From this point of view it will not be erring widely if the assumption be made that the effect of all the end-pieces does not exceed half the effect of all the staves.

Now in Cask III (unsatisfactory) the pieces including much or a fair amount of starch were exclusively staves, whereas in Cask V (satisfactory) they were exclusively end-pieces. Reckoning then the effect of the end-pieces as half that of the staves, the percentages in reference to all the wood in each cask become :—

—	M	F	LO	M + F	LO
Cask III	15	22	63	37	63
Cask V	16	2	82	18	82

In other words, Cask V has a much larger percentage of wood with little or no starch, and a much smaller (18) percentage of wood having a rich or fair amount of starch.

If we group the average figures given in the percentage table somewhat differently, as is shown below,—

—	*Starch.*		*Calcium oxalate.*	
	M + F	LO	m + f	lo
Unsatisfactory	48	52	57	43
Satisfactory	17	83	83	18

two probabilities are strongly suggested :—

(1) That unsatisfactory casks have more wood containing much or a fair amount of starch, and little or no calcium oxalate, than satisfactory casks.

(2) That the amount of starch in a piece varies inversely as the amount of calcium oxalate.

This last suggestion is, however, at variance with observations on the individual pieces, which, for instance, may have much starch and much calcium oxalate, or none of either, as recorded in the Tables in the Appendix. It must be pointed out again that the method of gauging the amount, especially of calcium oxalate, by mere examination of isolated microscopical sections, is unreliable.

Chemical Preparation.

It is obvious that the method of preparation of the casks before filling them with beer conceivably might determine whether or no the barrel shall taint the beer. In this connection, however, it may be pointed out that one firm sent for examination two of their casks, one satisfactory and the other unsatisfactory. If the treatment given to these two casks were *exactly* the same, it is obvious that something more than treatment decides the satisfactory or unsatisfactory nature of the cask.

B.—MICRO-ORGANISMS.

In view of the lack of sufficient time, and in view of the results obtained, only comparatively little attention was devoted to micro-organisms in the barrels.

Spoilt beer from unsatisfactory Casks I, II and III, and good beer from the satisfactory Cask V, was examined. Cultures were made from these on arrival, and at intervals of three or four days for two or three weeks.

Cultures were also made from the inner surfaces of the staves when the empty cask arrived, or immediately after emptying casks containing beer.

As media beer-wort agar and lemco-agar were used at first, but subsequently the former alone was employed.

In *all* cases colonies of three definite kinds of micro-organisms resulted. These were not critically identified, so that the names given are merely tentative.

(1) *Clostridium:* a bacterium very similar to *C. butyricum*, but not anaerobic. This micro-organism appeared capable of development when the supply of oxygen was scanty, as it developed not only on the surface, but deeper in the medium than did either of the two other micro-organisms. In Jörgenson's book on micro-organisms and fermentation the statement is made that some species of *Clostridium* thrive in the presence of oxygen.

(2) *Streptothrix:* a narrow filiform type. This appeared to increase later in the cultures, while *Clostridium* seemed to decrease.

(3) *Mycoderma* or *Bacillus Aceti:* forming typical frilled colonies, was present only in very small amounts, and did not seem to increase while the beer was deteriorating in flavour.

From casks 1 and 2 a few colonies of *Sarcina*, a spherical yellow bacterium, appeared, but did not develop from any of the other casks or beer.

The beer in Casks III (unsatisfactory) and V (satisfactory) yielded about the same number of colonies of the first three kinds of bacteria, so that these appeared to be equally numerous in good and bad beer.

In Lafar's *Handbook of Technical Mycology* it is stated that in good beer bacteria agreeing with the four kinds above mentioned are habitually present, but damage the beer only when very abundant.

There is, then, reason to suppose that not one of these four kinds of bacteria was generally responsible for deterioration in the beer; yet it is worthy of record that when Cask II (unsatisfactory) was emptied the staves and end-pieces were found to be richly dotted with white circular patches consisting of mixed colonies of *Clostridium*, *Streptothrix* and *Bacillus Aceti*.

Neither bacteria nor fungi were found inside the wood itself, either by microscopic examination or by cultures of fragments of staves or end-pieces.

As regards fungi, in a very few cases *Penicillium* or one of two species of *Eurotium* appeared in cultures from both good and bad beer. They were possibly casual infections from the laboratory.

C.—SUMMARY AND CONCLUSIONS.

(1) The staves and end-pieces were for the most part correctly cut in all casks save one. The method of cutting was not responsible for the deterioration of the beer.

(2) The wood used must be commercially described as heartwood, though it probably represented in many cases wood transitional between typical heartwood and sapwood, as it frequently contained much starch.

(3) All the wood used belonged to the most suitable class, that of the "White Oaks."

(4) Present knowledge (and especially the slow-grown nature of much of the wood) did not allow of exact determination of the species of wood used. Three types largely agreeing with the wood of *Quercus alba* were regularly seen, and all three occurred in both satisfactory and unsatisfactory barrels, between which the sole difference worthy of note was that in the unsatisfactory barrels there was a higher percentage of type *a*, and a corresponding lower percentage in the dubious pieces that could not be referred to any type.

(5) Tannin was present always in the walls of the constituents of the wood, which thus agreed with the heartwood of the two common European oaks.

(6) Starch was generally more abundant in unsatisfactory barrels. But variations in its quantity did not run side by side with differences in the types (*a*, *b*, *c*, and *doubtful*). The amount of starch, therefore, did not aid in identification of the species.

Starch did not lead to deterioration of the beer by providing food material for fungi and bacteria in the wood, for these latter were never found in staves or end-pieces. It is possible that some directly or indirectly tainting substance varies in quantity with the starch.

The differences in the amount of starch may have been due to difference in the season of felling, or to the pieces having been cut from heartwood of different ages.

It is thus conceivable that the wood may be unsatisfactory because it is from :—

(*a*) An inappropriate species.
(*b*) A tree felled at the wrong season.
(*c*) Heartwood that is too young.

Only in the United States of America can these three possibilities be investigated, and only there can be decided the further questions as to the practicability of selecting and securing appropriate species for felling, of felling these at appropriate seasons, and of selecting heartwood of the proper age (if such exist) It is therefore proposed that the results of this research shall be communicated to the Forestry Department of the United States, and that this Department be invited to aid in solving the problem.

(7) As a whole the amount of calcium oxalate appeared to vary inversely as that of starch ; but the method employed, that of mere inspection of sections, is not quantitatively reliable, and in individual staves such an inverse quantitative relation did not by any means reveal itself.

(8) The kinds of bacteria tentatively named *Clostridium*, *Streptothrix*, and *Bacillus Aceti* occurred both in the good and in the bad beer,

and did not differ appreciably in comparative numbers in the two beers. There is no reason to regard these or other bacteria (*Sarcina* occasionally present) as causing the deterioration.

(9) The fungi that appeared in some cultures were not regular in occurrence, and possibly were mere casual infections from the outside (laboratory air).

(10) The question as to whether the previous treatment of the wood is in any way responsible for deciding whether or not it shall taint the beer lay outside the scope of this research. It may, however, be pointed out that it is conceivable that difference of treatment in the country of origin (artificial or natural seasoning), or in this country ("pickling" and so forth), might thus play a part in determining the satisfactory or unsatisfactory nature of the wood or cask. It must, however, be recorded that in this research one firm supplied an unsatisfactory and a satisfactory cask. Obviously, too, the methods of transport and storage of the staves and end-pieces can have their effects. It would appear advisable to draw the attention of the Forestry authorities of the U.S.A. to this last suggestion.

APPENDIX.

Histological Method.

Small cubical pieces of wood were cut from each of the staves and end-pieces and placed in water. Air was extracted by an air-pump until they sank in the water. The cubes were transferred to acetone, in which they were kept for at least two hours. They were then transferred to a solution containing 12 grammes of cellulose acetate in 100 cubic centimetres of acetone, and were kept in this at a temperature of 40° C. for a fortnight. From them sections were cut, by means of a microtome, in three planes at right angles, viz., transverse, radial, and tangential: the sections were 10 to 15 μ in thickness (averaging therefore about 1/2000 inch in thickness).

TABLES.

Explanation of Symbols.

Cell-Contents.

——	*Starch.*	*Calcium oxalate.*
None	O	o
Very scanty	vL	vl
Scanty	L	l
Fair	F	f
Much	M	m
Very much	vM	vm

Measurements.

m/m = millimetre.
μ = 1/1000 millimetre.

CASK II.-

No. of Stave or End-piece.	Cell Contents. Amount.		Annual Ring.	Spring-vessels.		
	Starch.	*Calcium oxalate.*	*Width, m/m.*	*No. of tangential rows*	*Arrangement.*	*Shape.*
1	F	o	·8–1·2	1, rarely 2	Rather crowded	Round or ov[a] radially
2	F	l	1·3–2·9	2, rarely 3	As 1	Round ....
3	M	f	1·9–2	2	As 1	As 1 ....
4	L	f	2·5–3	2	As 1	As 2 ....
5	F	f	1–1·2	2–3	As 1	As 1 ....
6	F	m	1·5–2·5	1–2	As 1	As 2 ....
7	L	m	2–2·5	1–2	As 1	As 2 ....
8	F	f	·8–1·3	1–2	As 1	As 1 ....
9	L	m	2–3·3	2–3	Very crowded	Radially oval
10	M	m	3	2	As 1	As 2 ....
11	F	m	·9–1	1	Very isolated	Tangentially ov
12	M	m	1·5–2·5	1–2	As 1	As 2 ....
13	vM	o	1·5–1·9	1–2	As 1	As 1 ....
14	O	l	1·2–1·8	1–2	As 1	Round or ova tangentially
15	L	f	·8–1·3	1, rarely 2	As 11	As 11 ....
16	vM	l	1·0–1·3	1–2	As 1	As 9 ....
17	vL	f	1·3–2	1, rarely 2	As 1	As 1 ....
18	vM	l	·9–1·4	1	As 11	As 11 ....
19	M	l	1·2–1·5	1–2	As 1	As 9 ....
20	F	f	2–2·1	1–2	As 9	As 9 ....
21	vM	l	·9–1·9	1, rarely 2	As 11	As 11 ....
A (a)	vM	l	1·5	2–3	As 9	As 9 ....
A (b)	vM	l	·7–1	1	As 11	As 11 ....
A (c)	F	l	1–1·3	1	Rather isolated	As 11 ....
A (d)	vM	m	2	2	As 1	As 1 ....
B (a)	L	m	1·3–1·5	1–2	As 1	As 9 ....
B (b)	L	f	1·8–3	2, rarely 3	As 9	As 9 ....
B (c)	L	f	1·5–2·1	2	As 9	As 9 ....
B (d)	L	f	2–2·5	2	As 9	As 11 ....

Tannin present throughout.

Cleavage bad throughout, in a number of staves almost tangential.

UNSATISFACTORY.

Summer-vessels (arrangement).		Parenchyma (arrangement).		Type.
Nature of radial bands.	*Distance apart of radial bands.*	*Nature of tangential rows.*	*Distance apart.*	
Very broad, oblique	Rather far apart	Uniseriate, distinct and regular	Rather far apart	a
Very broad, rarely oblique	Rather near	Uniseriate, indistinct and irregular	Near together	a
As 2	Near together	Uniseriate or biseriate, irregular	As 2	a
Narrow, straight	As 3	Biseriate, irregular	As 2	c
So much spring-wood formed that arrangement is obscured		So much spring-wood that arrangement is obscured		?
Narrow, oblique	Far apart	Uniseriate, distinct, irregular	As 1	a
As 1	As 1	As 3	As 2	a
Forms a continuous tangential band		Where an arrangement can be made out, appears scattered		?
As 4	As 3	As 4 or scattered	Scattered	c
As 4	As 3	Scattered		c
Very broad, very oblique	Very far apart	Uniseriate, very distinct, irregular	Very far apart	b
As 4	As 3	As 10	As 10	c
As 2	As 3	As 1	As 1	a
As 1	As 1	As 1	As 1	a
As 1	As 1	As 1	As 1	b ?
Broad, straight	As 3	As 1	As 1	c
As 16	As 3	As 1	As 1	c ?
As 6	As 11	As 11	As 11	b
As 1	As 1	As 1	As 1	a
As 16	As 3	As 2	As 2	c
As 6	As 11	As 11	As 11	b
As 1	As 3	As 10	As 10	c
As 6 or 11	As 11	As 3	As 2	b ?
As 1	As 1	As 3	As 1	a
As 16	As 3	As 10	As 10	c
As 1	As 1	As 10	As 10	c
As 16	As 3	As 10	As 10	c
As 16	As 3	As 6	As 1	c
As 16	As 3	As 4	As 2	c

CASK III.—

No. of Stave or End-piece.	Cell Contents. Amount.		Annual Ring.	Spring-vessels.		
	Starch.	*Calcium oxalate.*	*Width, m/m.*	*No. of tangential rows*	*Arrangement.*	*Shape.*
1	L	o	·8–1	1	Rather crowded	Oval radially ....
2	M	l	1–1·5	1	As 1	Round ....
3	L	f	2	1–2	As 1	Round or oval radially
4	F	l	1·5–2	1	As 1	As 2 ....
5	F	m	3–4	1–2	Very crowded	As 1 ....
6	L	l	1	1–2	As 1	As 2 ....
7	Rather L	f	2	1–2	As 1	As 2 ....
8	M	f	1·5–1·8	2	As 1	As 3 ....
9	L	f	3–3·5	2–3	As 5	As 1 ....
10	L	f	1·3–1·6	1–2	As 1	As 2 ....
11	F	l	1·1–1·8	1–2	Isolated	Round or oval tangentially
12	M	l	1·5–2	1–2	As 1	As 3 ....
13	L	f	1–1·5	2–3	As 5	As 2 ....
14	O	o	1·5–2	1–2	As 5	As 1 ....
15	F	m	1·5–2	1–2	Very isolated	Oval tangentially
16	L	f	2·2–2·6	2–3	As 1	As 1 ....
17	L	l	1·8–2	2–3	As 1	As 3 ....
A 1	L	m	·8–1·8	1–2	As 11	As 2 ....
A 2	O	l	1	1	As 15	As 15 ....
A 3	O	f	·6–1·2	2	As 1	As 3 ... .
A 4	M	m	·7–1·2	1–2	As 5	As 1 ....
A 5	O	m	2–4	2	As 5	As 1 ....
A 6	O	m	2·5–3·2	2	As 5	As 1 ....
B 1	O	m	1·5–2	2	As 1	As 2 ....
B 2	O	f	·8–1·3	1–2	As 11	As 15 ....
B 3	L	m	2–2·5	1–2	As 1	As 2 ....
B 4	L	m	1·8–3	2–3	As 11	As 2 ....
B 5	O	m	3	1–2	As 11	As 2 ....
B 6	L	m	2–2·3	1	As 11	As 11 ....

UNSATISFACTORY.

Summer-vessels.		Parenchyma.		Type.
Nature of radial bands.	*Distance apart of radial bands.*	*Nature of tangential rows.*	*Distance apart.*	
Ring narrow and ar	rangement obscure	Narrowness of ring ment	obscures arrange-	?
In broad, sometimes oblique rows	Fairly near together	Uniseriate or biseriate, distinct and irregular	Rather near	a
Narrow, straight	Very near	Biseriate or s	cattered	c
As 2	As 2	As 2	As 2	a
As 2	As 2	As 3	—	c
Ring so narrow that scured	arrangement is ob-	As 1	As 1	a ?
As 3	Rather far apart	Biseriate	Rather far apart	a
Form tange	ntial bands	As 2	Rather far apart	a
As 3	As 2	As 3	As 3	c
As 8	As 8	As 7	As 7	a
Broad, oblique	As 7	Uniseriate, distinct	Far apart	b
Broad, straight	As 3	As 2	As 2	a ?
As 12	As 3	As 3	As 3	c
As 2	As 2	As 7	As 7	c ?
Narrow, very oblique	Very far apart	As 11	As 11	b
As 12	As 3	Very scatt	ered	c
As 2	As 2	As 3	As 3	c ?
As 15	As 15	As 11	As 11	b
As 11	As 11	Biseriate, distinct....	As 11	b
As 11	As 2	As 2, but not so distinct	As 2	a
As 6	As 6	As 6	As 6	?
As 3	As 3	Uniseriate, indistinct or scattered	As 2	c
As 12	As 3	As 16	As 16	c
As 12	As 3	As 16	As 16	c
As 11	As 7	As 3	As 3	c ?
As 3	As 3	As 3	As 3	c
As 3	As 3	As 16	As 16	c
As 3	As 3	As 16	As 16	c
As 3	As 3	As 16	As 16	c

CASK IV.—

No. of Stave or End-piece.	Cell Contents. Amount.		Annual Ring.	Spring-vessels.		
	Starch.	*Calcium Oxalate.*	*Width m/m.*	*No. of tangential rows*	*Arrangement.*	*Shape.*
1	L	m	·8–1·5	1–2	Rather crowded	Round ....
2	O	m	1·5–2	2–3	As 1	As 1 ....
3	O	f	2	2–3	Very crowded....	Radially oval ....
4	L	l	1·9–2·1	1–2	Isolated	Tangentially oval
5	O	l	1·5–2	1–2	As 4	As 4 ....
6	L	f	1–2	2–3	As 1	As 1 ....
7	F	f	1–1·7	1–2	Very isolated .. .	As 4 ....
8	L	f	·8–1·5	1–2	As 1	As 1 ....
9	L	m	1·5	2	As 1	As 3 ....
10	L	m	1–2	1–3	As 1	Round or radially oval
11	O	m	1·2–1·7	1–2	As 3	As 3 ....
12	L	f	1·5	1–2	As 4	As 4 ....
13	L	f	1–1·8 usually.	1–2	As 7	As 4 ....
14	L	f	1·5–1·8	1–2	As 7	As 4 ....
15	F	m	2	1–2 usually 1	As 1	As 1 ....
16	O	l	1·8–2	1–2	As 4	As 1 ....
17	L	m	1·5	1–2	As 1	As 3 ....
18	O	m	1·8–2	1–2	As 1	As 1 ....
19	L	f	·5	1	As 1	As 1 ....
20	L	f	1–1·5	1–2	As 1	As 1 ....
21	L	f	·5–·7	1–2	As 1	As 1 ....
A 1	L	l	2–3	1–2	As 1	As 1 ....
A 2	L	m	·7–1	2	As 1	As 1 ....
A 3	L	f	·9–1·1	1–2	As 7	As 4 ....
A 4	L	m	1	1–2	As 1	As 1 ....
A 5	L	l	1·5–2·1	1–2	As 3	As 10 ....
B 1	L	m	2–3	3	As 3	As 3 ....
B 2	L	m	2·5–4·5	2	As 3	As 3 ....
B 3	O	m	1–2	1–2	As 1	As 1 ....
B 4	O	m	2	2–3	As 3	As 3 ....
B 5	L	f	2–2·5	2–3	As 3	As 3 ....

Tannin present throughout.
Cleavage radial throughout.

SATISFACTORY.

Summer-vessels.		Parenchyma.		Type.
Nature of radial bands.	*Distance apart of radial bands.*	*Nature of tangential rows.*	*Distance apart.*	
Broad, may be oblique	Rather far apart	Indistinct, bi- or tri-seriate	Near	a
Broad, oblique	As 1	Indistinct, usually uniseriate	As 1	a
Broad, straight	Close together	Scatt	ered	c
Narrow, oblique	As 1	Fairly distinct, uni- or bi-seriate	As 1	a
As 1	As 1	As 4	As 1	a
As 1	As 1	As 4	As 1	a
As 4	Very far apart	Uniseriate, rather irregular, very distinct	Very far apart	b
As 1	As 1	Uniseriate, fairly distinct	As 1	a
As 3	As 3	As 3	As 3	c
As 3	As 3	As 3	As 3	c
As 1	As 1	As 4	As 1	a
As 4	As 7	As 7	As 7	b
As 4	As 7	As 7	As 7	b
As 4	As 7	As 7	As 7	b
As 3	As 3	As 4	As 1	a ?
As 2	As 1	As 4	As 1	a
As 2	As 1	As 7	As 7	a ?
As 2	As 3	As 3	As 3	c ?
Ring so narrow that scured	arrangement is ob-	Ring so narrow that scured	arrangement is ob-	?
As 2	As 1	As 2	As 1	a
As 19	As 19	As 19	As 19	?
Narrow, straight	As 3	As 3	As 3	c
Large amount of spr arrangement	ing-wood obscures	Large amount of spr arrangement	ing-wood obscures	?
As 3	As 3	As 3	As 3	c
As 2	As 1	As 4	As 1	a
As A1	As 3	As 3	As 3	c
As 3	As 3	As 3	As 3	c
As A1	As 3	As 3	As 3	c
As 2	As 1	As 4	As 1	a
As A1	As 3	As 3	As 3	c
As 3	As 3	As 3	As 3	c

CASK V.—

No. of Stave or End-piece.	Cell Contents. Amount.		Annual Ring.	Spring-vessels.		
	Starch.	*Calcium Oxalate.*	*Width, m/m.*	*No. of tangential rows.*	*Arrangement.*	*Shape.*
1	O	l	·8–1·8	1–2	Rather crowded	Round ....
2	L	f	1·2–1·8	1–2	As 1	As 1 ....
3	O	m	1·5–1·6	2–3	Very crowded	Oval radially ....
4	O	m	·8–1·5	1–2	Isolated	Oval tangentially
5	L	m	1–2	1–2	As 4	As 4 ....
6	L	f	1–1·5	1–2	As 1	As 1 ....
7	L	m	1·5–2	2–3	As 3	As 3 ....
8	L	m	·8–1·5	1–2	As 1	As 1 ....
9	O	m	2–4	2–3	As 3	As 3 ....
10	L	o	1–1·5	1–2	As 3	As 3 ....
11	O	m	1·8–2·1	1–2	As 1	As 1 ....
12	O	m	3–3·8	2	As 3	As 3 ....
13	L	f	2–2·6	3	As 3	As 3 ....
14	L	f	1–1·8	2–3	As 3	As 3 ....
15	O	m	2–3	2–3	As 3	As 3 ....
16	O	m	1–2·5	1–2	As 1	As 1 ....
17	L	m	3–4	1–2	As 1	As 1 ....
18	O	m	1·2–2	1–2	As 1	As 1 ....
19	L	m	1·2–1·8	1–2	As 3	As 3 .... ..
20	L	m	1–1·5	2	As 3	As 3 ....
A 1	vM	l	2–2·5	1–2	As 1	As 1 ....
A 2	vM	l	·9–1·8	1–2	As 3	As 3 ....
A 3	M	f	1·5–3	1–2	As 3	As 3 ....
A 4	vM	o	1·5	1–2	As 1	As 1 ....
A 5	M	l	1·5–1·8	2–3	As 3	As 3 ....
B 1	L	m	·9–1·6	1	As 4	As 1 ....
B 2	M	f	1–1·8	1–2	As 3	As 3 ....
B 3	M	m	1–1·8	3	As 3	As 3 ....
B 4	F	o	1·1–2·1	1–2	As 3	As 3 ....
B 5	vM	f	1–1·7	1–2	As 3	As 3 ....

Tannin present throughout. Cleavage radial throughout.

Tyloses present throughout.

SATISFACTORY.

Summer-vessels.		Parenchyma.		Type.
Nature of radial bands.	*Distance apart of radial bands.*	*Nature of tangential rows.*	*Distance apart.*	
Narrow, rather oblique	Rather far apart	Indistinct, biseriate	Near	a
Broad, rather oblique	As 1	Fairly distinct, irregular, biseriate	As 1	a
As 2	Near together	Scattered		c
Narrow, very oblique	Very far apart	Very distinct, uniseriate or biseriate	Very far apart	b
Broad, oblique	As 4	As 4	As 4	b
As 2	As 1	As 2	As 1	a
Broad, straight	As 3	As 3	As 3	c
As 2	As 1	Very distinct, usually uniseriate	As 4	a ?
Narrow, straight	As 3	As 3	As 3	c
As 2	As 1	As 2	As 1	a ?
As 1	As 1	Fairly distinct, bi- or tri-seriate	As 1	a
As 9	As 3	As 3	As 3	c
As 7	As 3	As 3	As 3	c
As 7	As 3	As 3	As 3	c
As 7	As 3	As 3	As 3	c
As 2	As 1	As 11	As 1	a
As 7	As 3	Very broad bands, 3 or 4 rows of cells	As 1	c ?
As 2	As 1	As 8	Rather far apart	a ?
Very broad rows, usually forming a tangential band		Arrangement obscure		?
Summer-wood so narrow that arrangement is obscured		Summer-wood so narrow that arrangement is obscured		?
As 9	As 3	As 3	As 3	c
Ring narrow, arrangement obscure		As 3	As 3	c ?
As 9	As 3	As 3	As 3	c
As 7	As 3	As 3	As 3	c
As 9	As 3	As 3	As 3	c
As 2	As 1	As 17	As 1	a
As 9	As 3	As 3	As 3	c
As 20	As 20	As 20	As 20	c ?
As 9	As 3	As 3	As 3	c
As 7	As 3	As 3	As 3	c

TABLES GIVING THE AMOUNTS OF STARCH (*STA*) AND CALCIUM OXALATE (*CA*), AND NUMBERS OF PIECES CONTAINING THE RESPECTIVE AMOUNTS.

Cask I.—Unsatisfactory.

—	*a*		*b*		*c*		*Doubtful.*	
	Sta.	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*
Staves	M M M M M M F L L L L L L L	m l l o o o l m m m f f f l	M F L L L L	l l m m l l	L	l	F L L	f l l
End-pieces					F F F F F L L L	m l l o o m f o		
Total Staves (24)	M 6 F 1 L 7 — 14	m 4 f 3 lo 7 — 14	M 1 F 1 L 4 — 6	m 2 f 0 l 4 — 6	M 0 F 0 L 1 — 1	m 0 f 0 l 1 — 1	M 0 F 1 L 2 — 3	m 0 f 1 l 2 — 3
Total end-pieces (8)	O	O	O	O	M 0 F 5 L 3 — 8	m 2 f 1 lo 5 — 8	O	O
Total (all pieces) (32)	M 6 F 1 L 7 — 14	m 4 f 3 lo 7 — 14	M 1 F 1 L 4 — 6	m 2 f 0 l 4 — 6	M 0 F 5 L 4 — 9	m 2 f 1 lo 6 — 9	M 0 F 1 L 2 — 3	m 0 f 1 l 2 — 3

—	*Number of Pieces.*				*Percentages.*			
	a	b	c	Doubt.	a	b	c	Doubt.
Aggregate Totals (32)—Type....	14	6	9	3	44	19	28	9
Starch	M 7	F 8	LO 17		M 22	F 25	LO 53	
CaOx	m 8	f 5	lo 19		m 25	f 16	lo 59	

Cask II.—Unsatisfactory.

—	*a*		*b*		*c*		*Doubtful.*	
	Sta.	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*
Staves	M M M F F F L O	f l o m l o m l	M M F	l l m	M M M F L L	m m l f m f	F F L L	f f f f
End-pieces	F	l			M M L L L L	m l m f f f	M	l
Staves Total (21)	M 3 F 3 LO 2 — 8	m 2 f 1 lo 5 — 8	M 2 F 1 L 0 — 3	m 1 f 0 l 2 — 3	M 3 F 1 L 2 — 6	m 3 f 2 l 1 — 6	M 0 F 2 L 2 — 4	m 0 f 4 l 0 — 4
End-pieces Total (8)	M 0 F 1 L 0 — 1	m 0 f 0 l 1 — 1			M 2 F 0 L 4 — 6	m 2 f 3 l 1 — 6	M 1 F 0 L 0 — 1	m 0 f 0 l 1 — 1
All pieces (29)	M 3 F 4 LO 2 — 9	m 2 f 1 lo 6 — 9	M 2 F 1 L 0 — 3	m 1 f 0 l 2 — 3	M 5 F 1 L 6 — 12	m 5 f 5 l 2 — 12	M 1 F 2 L 2 — 5	m 0 f 4 l 1 — 5

—	*Numbers of Pieces.*				*Percentages.*			
	a	b	c	Doubt.	a	b	c	Doubt.
Aggregate Totals (29)— Type	9	3	12	5	31	10	41	17
Starch	M 11	F 8	LO 10		M 38	F 28	LO 34	
CaOx	m 8	f 10	lo 11		m 28	f 34	lo 38	

Cask III.—Unsatisfactory.

—	*a*		*b*		*c*		*Doubtful.*	
	Sta.	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*
Staves	M M F F L	f l f l f	F F	m l	F L L L L	m f f f f	M L L L O	l l l o o
End-pieces	O	f	L O	m l	L L L O O O O	m m m m m m m	M O	m f
Total Staves (17)	M 2 F 2 L 1 — 5	M 0 f 3 l 2 — 5	M 0 F 2 L 0 — 2	m 1 f 0 l 1 — 2	M 0 F 1 L 4 — 5	m 1 f 4 lo 0 — 5	M 1 F 0 LO 4 — 5	m 0 f 0 lo 5 — 5
End-pieces Total (12)	M 0 F 0 LO 1 — 1	m 0 f 1 l 0 — 1	M 0 F 0 LO 2 — 2	m 1 f 0 lo 1 — 2	M 0 F 0 LO 7 — 7	m 7 f 0 lo 0 — 7	M 1 F 0 LO 1 — 2	m 1 f 1 lo 0 — 2
All pieces Total (29)	M 2 F 2 LO 2 — 6	m 0 f 4 l 2 — 6	M 0 F 2 LO 2 — 4	m 2 f 0 l 2 — 4	M 0 F 1 LO11 — 12	m 8 f 4 lo 0 — 12	M 2 F 0 LO 5 — 7	m 1 f 1 lo 5 — 7

—	*Numbers.*				*Percentages.*			
	a	b	c	Doubt.	a	b	c	Doubt.
Aggregate Totals (29)— Type	6	4	12	7	21	14	41	24
Starch	M 4	F 5	LO 20		M 14	F 17	LO 69	
CaOx	m 11	f 9	lo 9		m 38	f 31	lo 31	

Cask IV.—Satisfactory.

—	*a*		*b*		*c*		*Doubtful.*	
	Sta.	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*
Staves ..	L L L L L O O O O	m f f f l m m l l	F L L L	f f f f	L L O	m m f	F L L O O	m m f m f
End-pieces	L O	m m			L L L L L L O	m m f f l l m	L	m
Staves Total (21)	M 0 F 0 LO 9 — 9	m 3 f 3 l 3 — 9	M 0 F 1 L 3 — 4	m 0 f 4 l 0 — 4	M 0 F 0 LO 3 — 3	m 2 f 1 lo 0 — 3	m 0 F 1 LO 4 — 5	m 3 f 2 lo 0 — 5
End-pieces Total (10)	M 0 F 0 LO 2 — 2	m 2 f 0 lo 0 — 2			M 0 F 0 LO 7 — 7	m 3 f 2 lo 2 — 7	M 0 F 0 L 1 — 1	m 1 f 0 l 0 — 1
All pieces Total (31)	M 0 F 0 LO11 — 11	m 5 f 3 l 3 — 11	M 0 F 1 L 3 — 4	m 0 f 4 l 0 — 4	M 0 F 0 LO10 — 10	m 5 f 3 lo 2 — 10	M 0 F 1 LO 5 — 6	m 4 f 2 lo 0 — 6

—	*Numbers.*				*Percentages.*			
	a	b	c	Doubt.	a	b	c	Doubt.
Aggregate Totals (31)— Type	11	4	10	6	35	13	32	20
Starch	M 0	F 2	LO 29		M 0	F 6	LO 94	
CaOx	m 14	f 12	lo 5		m 45	f 40	lo 16	

Cask V.—Satisfactory.

—	*a*		*b*		*c*		*Doubtful.*	
	Sta.	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*	*Sta.*	*Ca.*
Staves	L L O O O	f f m m l	L O	m m	L L L O O O O	m f f m m m m	L L L L L O	m m m m o m
End-pieces	L	m			M M M M M M F	f f f l l o o	M M	m l
Staves Total (20)	M 0 F 0 LO 5 — 5	m 2 f 2 lo 1 — 5	M 0 F 0 LO 2 — 2	m 2 f 0 lo 0 — 2	M 0 F 0 LO 7 — 7	m 5 f 2 l 0 — 7	M 0 F 0 LO 6 — 6	m 5 f 0 lo 1 — 6
End-pieces Total (10)	M 0 F 0 LO 1 — 1	m 1 f 0 lo 0 — 1			M 6 F 1 LO 0 — 7	m 0 f 3 lo 4 — 7	M 2 F 0 LO 0 — 2	m 1 f 0 l 1 — 2
All pieces Total (30)	M 0 F 0 LO 6 — 6	m 3 f 2 lo 1 — 6	M 0 F 0 LO 2 — 2	m 2 f 0 lo 0 — 2	M 6 F 1 LO 7 — 14	m 5 f 5 lo 4 — 14	M 2 F 0 LO 6 — 8	m 6 f 0 lo 2 — 8

—	*Numbers.*				*Percentages.*			
	a	b	c	Doubt.	a	b	c	Doubt.
Aggregate Totals (30)— Type	6	2	14	8	20	7	47	27
Starch	M 8	F 1	LO 21		M 27	F 3	LO 70	
CaOx	m 16	f 7	lo 7		m 53	f 23	lo 23	

Satisfactory Pieces.

—	Type c.		Doubtful.	
	Sta.	Ca.	Sta.	Ca.
Pieces	L L L L	m m f o	F L L	f m m
Total	M 0 F 0 L 4 — 4	m 2 f 1 o 1 — 4	M 0 F 1 L 2 — 3	m 2 f 1 l 0 — 3

—	Numbers.		Percentages.	
	Starch.	Ca.	Starch.	Ca.
Aggregate Total	M 0 F 1 L 6 — 7	m 4 f 2 l 1 — 7	M 0 F 14 L 86	m 57 f 29 l 14

APPENDIX.

Copy of letter addressed by Professor Percy Groom, M.A., D.Sc., on behalf of the Research Fund Committee, to the Chief of the U.S.A. Forestry Department.

THE CHIEF OF THE FORESTRY DEPARTMENT,
WASHINGTON, U.S.A.

SIR,

I beg leave to send you herewith copies of two reports giving the results of investigations on beer casks made of American oak. I trust that you may be sufficiently interested in the main problem involved to consider favourably the suggestion that your department might co-operate in these investigations, in view of the fact that some of the questions involved can be answered only by further research in the United States.

These investigations, which were initiated by and carried out under the auspices of the Institute of Brewing, are based on the fact that whilst, in some cases, beer contained in casks made of American oak preserves its flavour, in other cases it rapidly becomes tainted.

The Institute is anxious to ascertain the cause, and, if possible, to determine the means of prevention of this deterioration, and I venture, therefore, to make the following comments upon the accompanying reports, viz. :—

Botanical Research.

It was found that the tainting was not caused by the method of cutting the staves and end-pieces, nor by the presence of sapwood, nor by micro-organisms entering the wood.

For reasons fully explained in my report, it was found impossible to identify exactly the kinds of oak wood or woods used, although it was found that in every case the wood used was that of one of the "White Oaks."

One fact of interest (which appears worthy of investigation from a botanical standpoint) was discovered, namely that the heartwood of which the staves, &c., were composed often contained large quantities of starch, and thus appeared to be rather of a nature transitional between heartwood and sapwood.

There appeared to be a possible relation between, respectively, the satisfactory and unsatisfactory nature of the staves, &c., and the amount of starch present in the wood. It was not possible to discover any relation between the amount of starch and the species of the wood, nor to ascertain if the wood rich in starch was the younger wood.

The tainting of the wood may be due to :—

(*a*) The use of an inappropriate species of oak.
(*b*) The felling of an appropriate species at an improper season.
(*c*) The use of heartwood of an appropriate species which is too young (being immediately within the sapwood) or, less probably, too old.

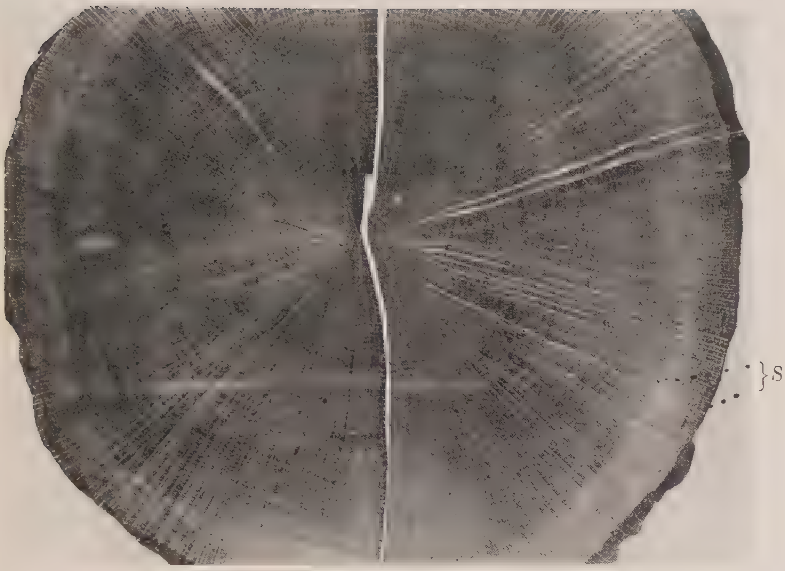

FIG. 1.—Transverse section of trunk of oak (reduced). S = sapwood.

FIG. 2.—Transverse section part of trunk of oak, showing annual rings (reduced).

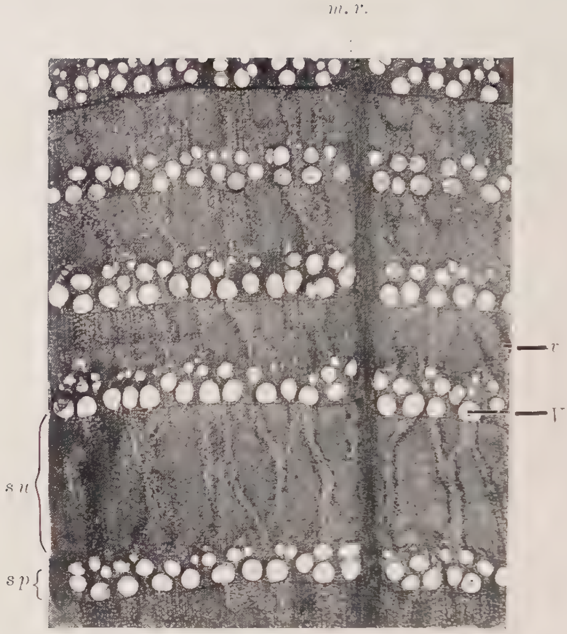

FIG. 3.—Transverse section of American oak-stave. (Magnification, 10 diameters.) V = large vessels (pores); v = small vessels; su = summer-wood; sp = spring-wood; $m.r.$ = thick medullary ray.

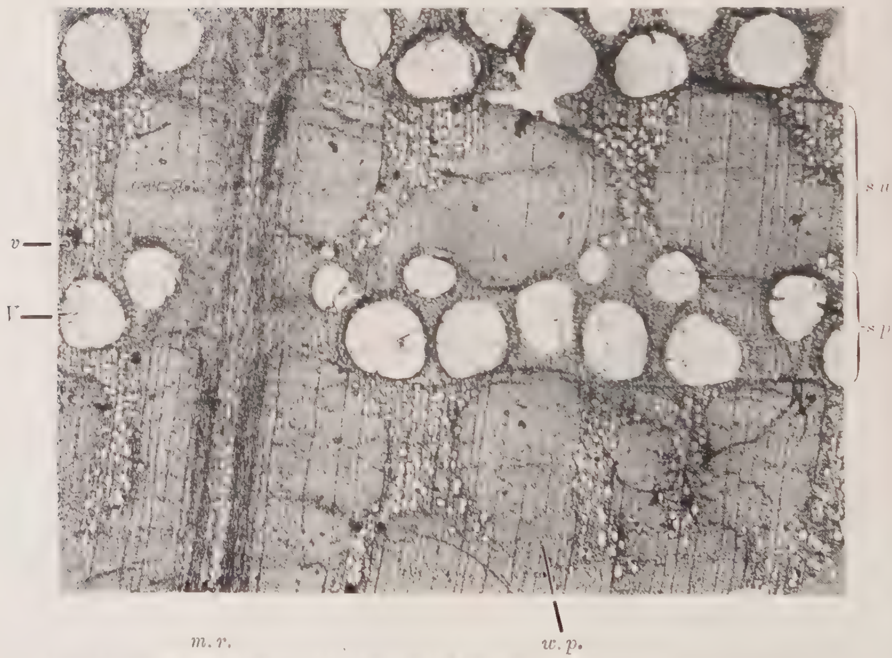

FIG. 4.—Transverse section of American oak-stave. (Magnification, 25 diameters.) $w.p.$ = wood-parenchyma, other letters as in Fig. 3.

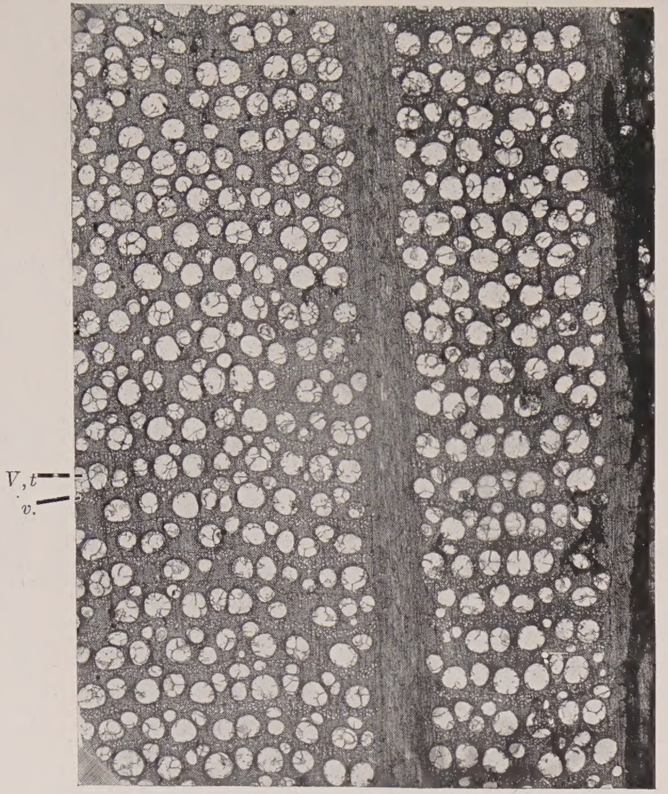

FIG. 5.—Transverse section of slow-grown American oak-stave with obliteration of the radial arrangement of the small vessels in the narrow summer-wood: V, t large vessels containing tyloses. (Magnification, 10 diameters.)

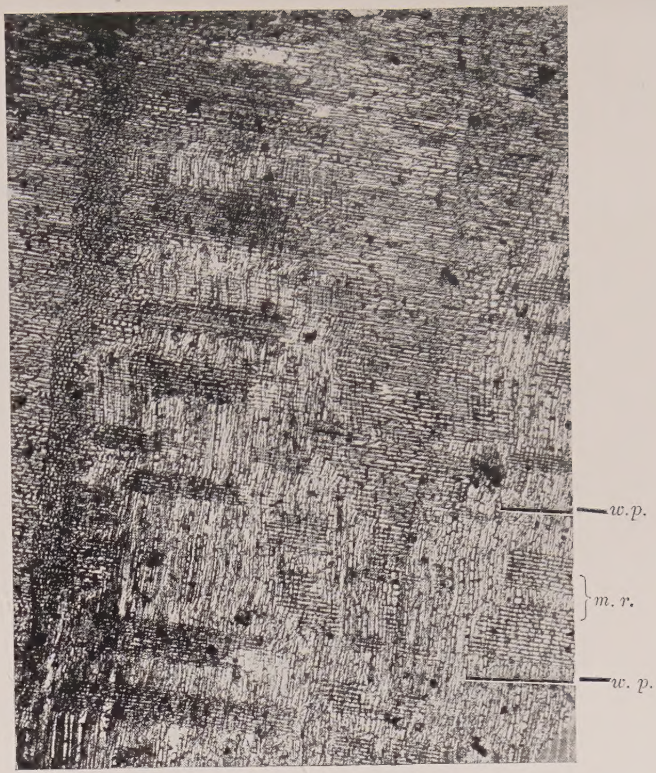

FIG. 6.—Radial longitudinal section of American oak-stave, especially showing the medullary rays (*m.r.*) and wood parenchyma (*w.p.*). (Magnification, 25 diameters.)

Fig. 7.—Tangential longitudinal section of American oak-stave, especially showing wide medullary ray (*m. r.*) and narrow ones ($m^1 r^1$), also narrow vessels (*v*). (Magnification, 25 diameters.)

These possibilities could be tested only by the felling of definitely determined species at different times of the year, and the preparation of staves and end-pieces from different parts of the wood of the trunk. If such staves and end-pieces were prepared, the Institute of Brewing would be most willing to have them made into casks and tested as regards their action on beer.

There is, however, a further problem, viz. :—if, eventually, it were proved that satisfactory casks could be made only from certain species, or from trees felled at a certain time, would it be possible either to secure accurate identification and selection by persons felling the trees, or, alternatively, to have the trees felled at the proper season ?

Other possibilities, outside the purely botanical ones, are likewise insoluble in this country. It is, for instance, conceivable that the kiln-drying of staves, or certain conditions of storage or transport, might convert satisfactory wood into wood that taints beer.

Biochemical Research.

The results attained so far are summarised on page 4 of Professor Schryver's report (*see* page 681 of the accompanying reprint from the Journal of the Institute), and attention is particularly directed to the 5th paragraph of his general conclusions, viz. :—

"(5) The differences between the values of the various timbers for cask-making appear to be due, not to any specific extractive which imparts a deleterious flavour to the beer, but rather to fundamental differences in the chemical and physical properties of the timbers themselves. It will be only possible to correlate the differences with the species, time of felling, conditions of growth, &c., where the exact history of each piece of timber examined is known. For this reason further pursual of some of this work would be best undertaken in the country of origin of the timbers, when some of the chemical methods of examination indicated in this report might prove of considerable diagnostic value in choosing timbers for cask-making."

The Commercial Aspect.

With regard to the commercial aspect of the question, it will, I think, be obvious to you that, if the investigations that we have commenced could be prosecuted to a successful issue, the future would hold out very promising possibilities as regards the supply to this country by the United States of America of material for cask-making. It will be known to you, of course, that many English brewers will not use American oak in the manufacture of their casks for fear of tainting their beers, and that, in cases where such wood is employed, the casks are seldom, if ever, used without first being lined with some chemical preparation. This lining, moreover, requires constant treatment and renewal, thus adding materially to the cost of manufacture. The selection of appropriate oak wood for the manufacture of casks is of paramount importance, and the Research Fund Committee of the Institute of Brewing desires me to express the hope that you will be able to carry our investigations to a profitable conclusion.

I am, Sir,

Yours faithfully,

(Signed) PERCY GROOM.